

ABSTRACT – NOT FOR PUBLICATION

A General Closed-Form Solution for the Lunar Reconnaissance Orbiter (LRO) Antenna Pointing System

Neerav Shah
NASA Goddard Space Flight Center

J.Roger Chen
K&D Research

Joseph A. Hashmall
a.i. solutions, Inc.

The National Aeronautics and Space Administration's (NASA) Lunar Reconnaissance Orbiter (LRO) launched on June 18, 2009 from the Cape Canaveral Air Force Station aboard an Atlas V launch vehicle into a direct insertion trajectory to the Moon. LRO, designed, built, and operated by the NASA Goddard Space Flight Center in Greenbelt, MD, is gathering crucial data on the lunar environment that will help astronauts prepare for long-duration lunar expeditions. During the mission's nominal life of one year its six instruments and one technology demonstrator will find safe landing sites, locate potential resources, characterize the radiation environment and test new technology. To date, LRO has been operating well within the bounds of its requirements and has been collecting excellent science data – images taken from the LRO Camera Narrow Angle Camera (LROC NAC) of the Apollo landing sites have appeared on cable news networks. A significant amount of information on LRO's science instruments is provided at the LRO mission webpage.

LRO's Attitude Control System (ACS), in addition to controlling the orientation of the spacecraft is also responsible for pointing the High Gain Antenna (HGA). A dual-axis (or double-gimbaled) antenna, deployed on a meter-long boom, is required to point at a selected Earth ground station. Due to signal loss over the distance from the Moon to Earth, pointing precision for the antenna system is very tight. Since the HGA has to be deployed in spaceflight, its exact geometry relative to the spacecraft body is uncertain. In addition, thermal distortions and mechanical errors/tolerances must be characterized and removed to realize the greatest gain from the antenna system. These reasons necessitate the need for an in-flight calibration. Once in orbit around the moon, a series of attitude maneuvers was conducted to provide data needed to determine optimal parameters to load onboard, which would account for the environmental and mechanical errors at any antenna orientation.

The nominal geometry for the HGA involves an outer gimbal axis that is exactly perpendicular to the inner gimbal axis, and a target direction that is exactly perpendicular to the outer gimbal axis. For this nominal geometry, closed-form solutions of the desired gimbal angles are simple to get for a desired target direction specified in the spacecraft body frame. If the gimbal axes and the antenna boresight are slightly misaligned, the nominal closed-form solution is not sufficiently accurate for computing the gimbal angles needed to point at a target. In this situation, either a general closed-form solution has to be developed for a mechanism with general geometries, or a correction scheme has to be applied to the nominal closed-form solutions. The latter has been adopted for Solar Dynamics Observatory (SDO) as

can be seen in Reference 1, and the former has been used for LRO. The advantage of the general closed-form solution is the use of a small number of parameters for the correction of nominal solutions, especially in the regions near singularities. Singularities here refer to cases when the nominal closed-form solutions have two or more solutions. Algorithm complexity, however, is the disadvantage of the general closed-form solution.

For calibration purpose a comprehensive kinematic model involving perturbations from the nominal geometry has been created. Simple parameterization of the pointing system produces a complete set of 11 calibration parameters - 9 misalignment angles and 2 biases. By modifying the parameter representation, redundancy was eliminated and a minimum set of 7 independent parameters defined. These can be as 5 misalignment angles and 2 biases. An algorithm to determine these parameters after launch has been developed and tested with simulated SDO data. The algorithm consists of a direct minimization of the root-sum-square of the differences between expected transmitted power and measured power, see Reference 1. For LRO, these misalignment angles and biases were re-parameterized to be consistent with the onboard kinematic model, but the same system was used.

This paper presents in detail the general closed-form solution for an arbitrary double-gimbaled pointing mechanism with non-orthogonal gimbal axes. It then discusses the issues related to applying the general algorithm for LRO. Test results as well as flight results are examined. Pre-calibration and post-calibration flight performance data observed for LRO are shown to improve pointing performance.

REFERENCES

1. **Hashmall, Joseph A.** *Calibration of Gimbaled Platforms: The Solar Dynamics Observatory High Gain Antennas*. Lanham : International Symposium on Spaceflight Dynamics, 2006.